RECENT RADIO MONITORING OF MICROQUASARS WITH RATAN-600 RADIO TELESCOPE

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ABSTRACT

We report about the multi-frequency (1-30 GHz) daily monitoring of the radio flux variability of the three microquasars: SS433, GRS1915+105 and Cyg X-3 during the period from September 2005 to May 2006.

1. We detected clear correlation of the flaring radio fluxes and X-rays 'spikes' at 2-12 keV emission detected in RXTE ASM from GRS1915+105 during eight relatively bright (200-600 mJy) radio flares in October 2005. The 1-22 GHz spectra of these flares in maximum were optically thick at frequencies lower 2.3 GHz and optically thin at the higher frequencies. During the radio flares the spectra of the X-ray spikes become softer than those of the quiescent phase. Thus these data indicated the transitions from very high/hard states to high/soft ones during which massive ejections are probably happened. These ejections are visible as the detected radio flares.

2. After of the quiescent radio emission we have detected a drop down of the fluxes (~20 mJy) from Cyg X-3. That is a sign of the following bright flare. Indeed such a 1 Jy-flare was detected on 3 February 2006 after 18 days of the quenched radio emission. The daily spectra of the flare in the maximum was flat from 1 to 100 GHz, using the quasi-simultaneous observations at 109 GHz with RT45m telescope and millimeter array (NMA) of Nobeyama Radio Observatory in Japan. The several bright radio flaring events (1-10 Jy) followed during this state of very variable and intensive 1-12 keV X-ray emission (~0.5 Crab), which being monitored in RXTE ASM program. We discussed the various spectral and temporal characteristics of the detected 180-day light curves from three microquasars in comparison with Rossi XTE ASM data.

Key words: microquasars; radio emission; X-rays; monitoring.

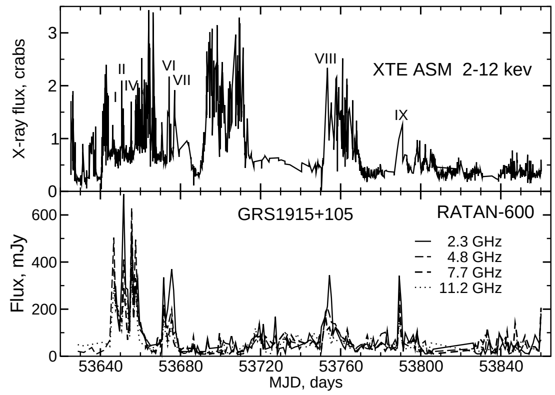

Figure 1. Light curves of GRS1915+105 at radio frequencies and at 2-12 keV from September 2005 to March 2006.

1. INTRODUCTION

Collimated high-velocity outflows of accreting matter in the narrow cones of the two-side relativistic jets, ejected from polar regions of accretion disks around black holes or neutron stars in the microquasars, are the effective sources of variable synchrotron emission in distinct clouds contained magnetic fields and energetic electrons. Only 15 microquasars are now detected in the Milky Way in the sample of 350 X-ray binaries. The ballistic tracks of these clouds (blobs) are directly visible as radio jets in VLA and VLBI maps of SS433, GRS 1915+105 and Cyg X-3. The time and frequency dependences in the light curves are the key for clear understanding and good probe test for models of the physical processes in cosmic jets. A comparison of the radio and X-ray data allow us to provide detailed studies. We have carried out the 250-day monitoring of the microquasars Cyg X-3, GRS 1915+105, and SS433, with the RATAN-600 radio telescope at 1-30 GHz from September 2005 to May 2006.

Table 1. Sensitivity of the RATAN-600 telescope.

λ, cm	31	13.0	7.6	3.9	2.7	1.38
ν, GHz	1.0	2.3	3.9	7.7	11.2	21.7
ΔS,mJy	30	10	3	10	10	15

Table 2. Flux densities for calibration sources, Jy

Source	Frequency, GHz					
name	1.0	2.3	4.8	7.7	11.2	21.7
1331+30	17.49	11.5	7.22	5.52	4.25	2.5
1345+12	6.5	4.26	2.95	2.25	1.82	0.94
1850-00	-	2.27	3.33	3.88	4.19	4.49
2105+42	0.95	3.04	5.05	5.86	6.10	5.71

2. OBSERVATIONS

We have carried out the 250-day almost daily monitoring observations of the microquasars Cyg X-3, GRS 1915+10, SS433, with RATAN-600 radio telescope at 1-22 GHz from September 2005 to May 2006. The measured multi-frequency light curves can be directly compared with series of the X-ray observatory RXTE Levine et al. [1]. We have used a standard continuum radiometer complex. The receivers at 3.9, 7.7, 11.2, and 21.7 GHz were equipped with closed-cycle cryogenic systems, which lowered the temperature of the first amplifiers (HEMT) to 15-20 K. Low-noise transistor amplifiers were installed in the 0.98- and 2.3-GHz radiometers. Table 1 presents the current mean sensitivity of the RATAN-600 telescope for a single transit of a source through the fixed antenna beam. The observations were made using the 'Northern sector' antenna of RATAN-600 radio telescope at the upper culmination of the sources.

The flux densities of the sources at all six frequencies were measured in a single observation. Note that the resolution of the telescope was quite sufficient to reliably distinguish SS433, GRS 1915+105 and Cyg X-3 against the Galactic background. Although interference sometimes prevented realization of the maximum sensitivity of the radiometers, daily observations of reference sources indicate that the error in the flux density measurements did not exceed 5-10% at 2.3, 3.9, and 11.2 GHz and 10-15% at 21.7 GHz.

The flux density calibration was performed using observations of 3C286 (1328+30), PKS 1345+12 and NGC7027 (2105+42). We have controlled the antenna gain with thermal source (HII region) 1850–00 in daily observation also. We took the fluxes for these sources from Aliakberov et al. [2], which, in turn, were consistent with the primary radio astronomy flux scale of Baars et al. [3] and with the new flux measurements of Ott et al. [4]. The reference source fluxes adopted for this observation cycle are presented in Table 2.

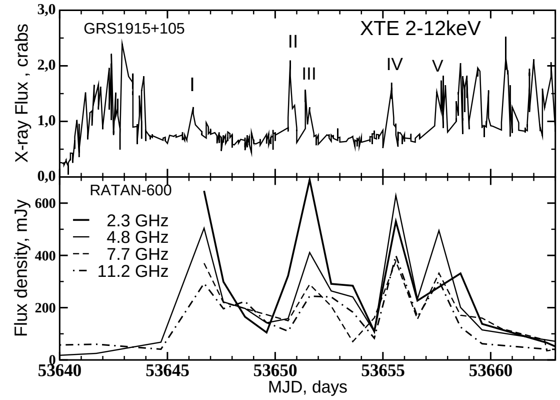

Figure 2. The radio and X-ray light curves of GRS1915+105 in October 2005.

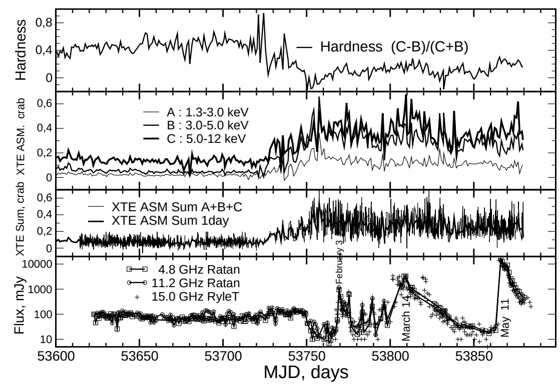

Figure 3. The RATAN and RXTE ASM light curves of Cyg X-3 from September 2005 to May 2006.

The recording of the data and the preliminary reduction and storage on a personal computer were carried out in the data collection package. The data reduction of the data FITS-files included background removal, convolution with the antenna beam, and Gaussian analysis. In this way, instantaneous spectra of the microquasars were constructed for each day from the measurements at the four-six frequencies.

3. RESULTS

3.1. GRS 1915+105: X-ray/radio correlation

The X-ray transient source GRS 1910+105 was discovered by Castro-Tirado et al. [5] with WATCH instrument on board GRANAT. In 1994, a superluminal motion of the jet had been detected from GRS 1915+105 (Mirabel F., Rodriguez, [6]), since then a new class of astrophysical objects 'Microquasars' was established.

Many X-ray observations of GRS 1910+105 revealed remarkable QPOs which are believed to arise in the accretion disk around a black hole. On the other hand, we are far form the full understanding of the jet phenomena. To

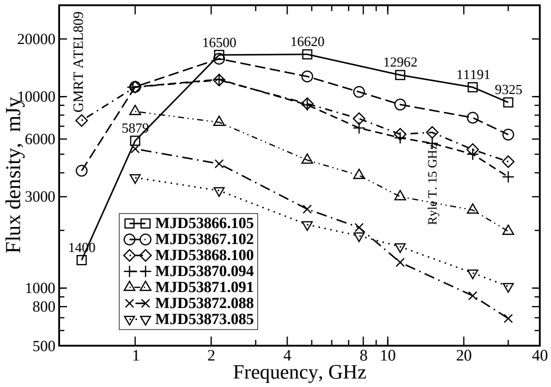

Figure 4. The daily spectra of Cyg X-3 during flare in May 2006.

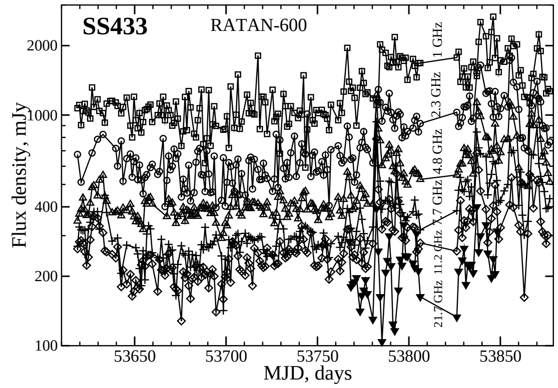

Figure 5. The light curves of SS433 from September 2005 to May 2006.

interpret the X-ray data correctly, long-term radio monitoring data are desirable. By reference to radio data, the activity and state of the source can be diagnosed. Furthermore, the massive jet ejection events, by which the source was recognized as a microquasar in the first place, can be predicted by means of radio monitoring. A massive jet ejection event from another microquasar, SS 433, was observed with RXTE with the help of radio monitoring (Kotani et al. [7]).

During the decay of the first flare (July 2000) Fender et al. [8] for the first time detected the quasi-periodical oscillations with P = 30.87 minutes at two frequencies: 4800 and 8640 MHz. The linear polarization of the oscillations was measured at a level 1-2 per cent with a flat spectrum.

In Fig.1 the radio and X-ray light curves are showed during the total set. The nine radio flares have the counterparts in X-rays. The radio spectrum was optically thin in the first two flares, and optically thick in third one (Fig.2). The profiles of the X-ray spikes during the radio flares are clearly distinguishable from other spikes because of its shape, it shows the fast-rise and the exponential-decay. The other X-ray spikes, which reflect the activity of the accretion disk, show an irregular pattern. During the radio flare, the spectra of the X-ray spikes become softer than those of the quiescent phase, by a fraction of $\sim$30%.

Miller-Jones et al. [9] have detected large-scale radio jet with VLBA mapping during an X-ray and radio outburst on 23 February 2006 (MJD53789.258). Then the optically thin flare with fluxes 340, 340, 342, 285, 206, and 153 mJy was detected at frequencies 1, 2.3, 4.8, 7.7, 11,2 and 21.7 GHz.

3.2. Cyg X-3: new long active period

During 100 days Cyg X-3 was in a quiescent state of $\sim$100 mJy (Fig.3). In December 2005 its X-ray flux began to increase and radio flux at 2-11 GHz increased also. Then the flux density at 4.8 GHz of the source was found to drop from 103 mJy on Jan 14.4 (UT) to 43 mJy on Jan 15.4 (UT), and to 22 mJy on Jan 17.4 (UT). The source is known to exhibit the radio flares typically with a few peaks exceeding 1-5 Jy following such quenched state as Waltman Waltman [10] have showed in the intensive monitoring of Cyg X-3 with the Green Bank Interferometer at 2.25 and 8.7 GHz. The source has been monitored from Jan 25 (UT) with the Nobeyama Radio Observatory 45m Telescope (NRO45m Telescope), the Nobeyama Millimeter Array (NMA), Yamaguchi-University 32-m Radio Telescope (YRT32m), and Japanese VLBI Network telescopes. On Feb 2.2 (UT), about 18 days after it entered the quenched state, the rise of a first peak is detected with the NRO45m Telescope and YRT32m. On Feb 3.2 (UT), the flux densities reached to the first peak at all the sampling frequencies from 2.25 GHz to 110.10 GHz (Tsuboi et al. [11]). The spectrum in maximum (3 February) of the flare was flat as measured by RATAN, NRO RT45m and NMA from 2 to 110 GHz. The next peak of the active events on 10 February reached the level of near 1 Jy again with a similar flat spectrum. Then three short-time flare have happened during a week. The flare on 18 February had the inverted spectrum with the same spectral index α=+0.75 from 2.3 to 22 GHz.

In the active period there were two powerful flares, March 14 to 3-5 Jy and May 11 to 12-16 Jy at 2-30 GHz. In the May flare fluxes have grown up by a factor $\sim$1000 during a one day. Such powerful ejection of relativistic electrons were detected with RATAN and by G. Pooley with Ryle telescope.

The change of the spectrum during the flare on May 11-19 followed to model of single ejection of the relativistic electrons, moving in thermal matter in the intensive WR-star wind. It stays in optically thin mode at the higher frequencies, meanwhile at lower frequency 614 MHz (Pal et al. [12], Fig.4). Cyg X-3 was in hard absorption due to thermal electrons in stellar wind.

The decay of the synchrotron radio flares and spectral variability follow prediction of a finite jets segment model, that was involved by Marti et al. [13] and by Hjellming et al. [14] for modeling the flaring of Cyg X-3 and SAX J1819-25 respectively. The typical ‘bubble' event follows by the optically thin power-law decay $\propto \nu^{\alpha}\, \mathrm{t}^{-\beta}$, where index α varies from –1 to 0, and index β varies from 1 to 6 according to the dependence from distance r: internal magnetic field H(r), thermal $\mathrm{N_{th}}$(r), relativistic $\mathrm{N_{rel}}$(r) electrons densities, and jet and expansion velocities $\mathrm{v_{jet}}$(r), $\mathrm{v_{exp}}$(r).

3.3. SS433: the light curves and spectra

The first microquasar SS433, a bright variable emission star was identified with a rather bright compact radio source 1909+048 located in the center of a supernova remnant W50. In 1979 moving optical emission lines, Doppler-shifted due to precessing mass outflows with 78000 km/s, were discovered in the spectrum of SS433. At the same time in 1979 have discovered a unresolved compact core and 1 arcsec long aligned jets in the MERLIN radio image of SS433. At present such a structure in microquasars is commonly named a radio jet. Different data do indicate a presence of a very narrow (about 1^o) collimated beam at least in X-ray and optical ranges. At present there is no doubt that SS433 is related to W50. A distance of near 5 kpc was later determined by different ways including the direct measurement of proper motions of the jet radio components.

Kotani et al. [7] detected the fast variation in the X-ray emission of SS433 during the radio flares, probably even QPOs of 0.11 Hz. Massive ejections during this active period could be the reason of such behavior. In Fig.5 the daily RATAN light curves are shown. Clearly the activity of SS433 began during the second half of the monitoring set. Some flares happened just before and after the multi-band program of the studies of SS433 in April 2006 (Kotani et al. [15]).

In Fig.6 the light curve during the bright flare in February 2006 are showed after subtracting a quiet spectrum $S_{\nu}[Jy] = 1.1\,\nu^{-0.6}[GHz]$. The delay of the maximum flux at 1 GHz is about 2 days and 1 day at 1 and 2.3 respectively relatively the maxima at the higher frequencies. Below in Fig.6 the spectra of the flare during first three days. We see the characteristic shift of turn-over of spectra to low frequency during the flare, clearly indicating the decrease of the absorption with time.

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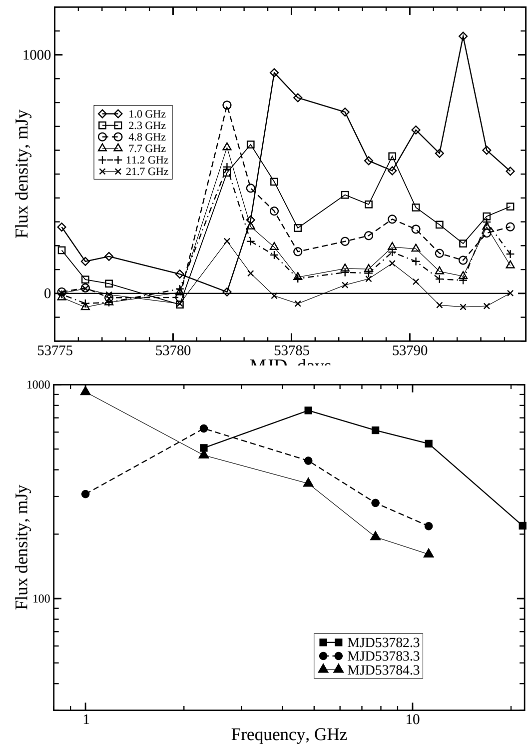

Figure 6. The light curves after subtracting a quiet spectrum of SS433 in February 2006 and the flaring spectra on 16-18 February 2006.

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